ARMY RESEARCH LABORATORY

Human Factors Integration: Cost and Performance Benefits on Army Systems

Harold R. Booher

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prepared by

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under contract

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Abstract

This report documents and, to the degree possible, quantifies the benefits of human factors integration (HFI) effort to selected Army programs. Four Army weapon systems were identified for documenting HFI lessons learned and quantitative benefits. These systems are two aviation systems, Comanche and Apache; one nuclear, biological, chemical (NBC) reconnaissance vehicle, Fox; and the Army's advanced howitzer program, Crusader. The Comanche aircraft provides the most comprehensive lessons learned for HFI, based on its application of the Army's manpower and personnel integration (MANPRINT) program from its inception. The Apache helicopter provides some quantitative examples of benefits from HFI applications on design and development of changes to a system already in the Army inventory. The Fox reconnaissance vehicle (XM93E1 NBC) demonstrates quantitative benefits and lessons learned from HFI applications on a non-major system. The Crusader was chosen because it illustrates the critical role played by HFI technologies in conducting realistic battlefield scenarios in war games.

Attention is given to the effects of HFI in five major areas:

1. The acquisition process
2. System design and development
3. Operational performance and testing
4. Cost avoidance
5. Safety benefits

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Purpose

This report documents and, to the degree possible, quantifies the benefits of human factors integration (HFI) effort to selected Army programs. Four Army weapon systems were identified for documenting HFI lessons learned and quantitative benefits. These systems are two aviation systems, Comanche and Apache; one nuclear, biological, chemical (NBC) reconnaissance vehicle, Fox; and the Army's advanced howitzer program, Crusader.

Methods

An initial survey of existing literature was conducted for HFI cost and performance benefit analysis. The relevant references are listed toward the end of this report. An analysis of the four selected systems was conducted using cost benefits literature results and discussions with personnel familiar with the cost benefit studies.

In all cases, the focus was upon the application of and early insertion of manpower and personnel integration (MANPRINT) tools, with an emphasis on quantifiable data that support performance increases and cost reduction.

Findings

The focus on the soldier philosophy enabled Comanche to advance not only human-machine interfaces but also the entire engine and airframe construction. HFI technology itself is advanced by research focused on an operational environment and the human-technology-organizational interfaces. New human figure modeling tools such as those employed on the Fox vehicle are continually being advanced as part of the HFI set of tools to answer such questions as work space layout, egress, and access to equipment in new or modified designs.

The Comanche, Fox, and Crusader case studies show the importance of HFI to the capability and validity of those simulations directed to questions about systems performance, accelerated acquisition processes, 21st century training techniques, and outcomes in warfighting scenarios.

The Comanche illustrated the numerous desirable acquisition processes that were made to work effectively because of HFI influence. The Fox vehicle case study shows that the benefits to

the acquisition process are not limited to new systems. Fox also shows the major benefits to non-major systems as well the ability of HFI to focus the testing on the critical mission-related performance areas identified by the models.

Longbow Apache HFI made more than 160 critical design improvements for the period evaluated. The acquisition category (ACAT)-III Fox vehicle could not have performed its missions in accordance with system requirements if HFI had not designed a new workstation. These two systems were modifications of existing systems, however, so the HFI potential was limited. To appreciate the full impact of HFI potential on system design, the Comanche is without comparison.

Comanche showed 91 lives saved and 116 disabling injuries avoided from HFI designs, compared to the predecessor aircraft. The Apache study did not calculate the number of lives and disabling injuries avoided, but two of the five problems, issues, and concerns (PICs) would have undoubtedly contributed to unnecessary loss of lives and disabling injuries, if they had not been corrected.

The three case studies with quantitative analysis of costs and savings make an interesting comparison. The Comanche offers both the greatest return on investment and total costs avoided. The Apache Longbow provides a very commendable savings and return on investment. Both Comanche and Apache returns are spread over 20 years. Fox showed that schedule time and costs (contract and operational test) in the near term as well as longer term manpower and training can be reduced. In fact, Fox demonstrates that smaller programs can literally be saved if HFI disciplines and technology have played a role in design, modeling, and simulation (see Table 1).

Table 1

Major Returns on Investment

System	Cost savings	Investment	Savings to investment ratio	Time (years)
Comanche	\$3.29 B	\$74.9 M	43.9:1	20
Apache Longbow	\$268.8 M	\$12.3 M	21.8:1	20
Fox	\$2-4 M	\$60 K	33.0:1	1

Conclusions

Technology Advancements

Technologies across the board are advanced rapidly through the influence of HFI. In aviation, not only human-machine interface, but also the entire engine and airframe construction were advanced by the focus on the soldier philosophy. HFI is the crucial link to make simulations reliable for the environments being simulated.

Acquisition Process Efficiencies

These studies showed that HFI enabled numerous desirable acquisition processes to work effectively. These benefits are not limited to new systems. HFI modeling can be used to support Operational Test and Evaluation Command (OPTEC) with their operational assessment of a system and reduce testing and evaluation (T&E) costs. Also, training and testing can be made more effective by integrating real and simulated systems in a complete battle lab environment.

System Design Enhancements

These case studies indicate clearly that HFI can be applied to enhance system designs appreciably, regardless of the stage of development or how large the system is.

Safety Increases

Safety was greatly improved by the MANPRINT teams on both the Comanche and Apache. Comanche showed 91 lives saved and 116 disabling injuries avoided from HFI designs, compared to the predecessor aircraft.

Major Returns on Investment

These studies show that considerable manpower, personnel, training and operational test and evaluation funds can be saved if HFI disciplines and technology have played a role in design, modeling, and simulation.

HUMAN FACTORS INTEGRATION: COST OF AND PERFORMANCE BENEFITS TO ARMY SYSTEMS

INTRODUCTION

Over the past decade, the U.S. Army has developed methodologies for integrating human factors into material acquisition. These methodologies have been implemented into Army systems as part of the Army's manpower and personnel integration (MANPRINT) program and the Department of Defense (DoD)'s human system integration (HSI) program. The human factors integration (HFI) methodologies cover a vast range of techniques. HFI includes top level methods useful to Army leaders in making major program decisions such as those associated with systems affordability. HFI also has an array of intermediate methods such as those directed toward system performance effectiveness trade-offs among manpower, personnel, training, and system design parameters. Still another type of HFI methodology is specifically applied to the human-machine interface, sometimes referred to as human systems interface technology. These methodologies have been applied to many Army programs to varying degrees and with varying levels of success. Several of these successes, as in the case of the Comanche helicopter, have been extremely impressive. More systematic cross-program documentation and assessment of HFI successes are needed, however, to convey a better understanding of the lessons learned and benefits provided to Army weapon systems. This report documents and, to the degree possible, quantifies the benefits of HFI effort to selected Army Programs. Four Army weapon systems were identified for documenting HFI lessons learned and quantitative benefits. These systems are two aviation systems, Comanche and Apache; one nuclear, biological, chemical (NBC) reconnaissance vehicle, Fox; and the Army's advanced howitzer program, Crusader.

The Comanche aircraft provides the most comprehensive lessons learned for HFI, based on its application of the Army's MANPRINT program from its inception. The report by Minninger, Skonieczny, and Yawn (1995) describes the various ways in which the Army's MANPRINT and DoD's HSI programs influenced the Comanche design and development program. The Comanche is the first HSI program in any of the services to have systematically applied human factors integration principles, skills, and technology from the beginning. The Comanche illustrates the entire range of benefits possible from a full application of HFI policy, procedures, skills, and technology. In addition to assuring a much improved design, which greatly increases the probability that the Comanche will be able to satisfactorily perform all its intended missions, a dramatic $3.2 billion in operations and supports costs will be avoided in manpower, personnel, training, and safety, compared to the costs of continuing with existing

aircraft. Additionally, at least 90 soldiers' lives will be saved and 116 disabling injuries will be avoided by introducing the Comanche with HFI designs.

The Apache helicopter provides some quantitative examples of benefits from HFI applications on design and development of changes to a system already in the Army inventory. In an era of few new systems, it is important to understand the contributions of HFI to systems considered nondevelopmental items (NDI) or planned product improvement (PPI), where the opportunity does not exist to make major changes early in the design process as with the Comanche. Although the contributions may not be as dramatic as possible with completely new systems, any advantages provided by HFI can be realized much earlier by the soldiers in the field. An HFI study (Irving, Hampton, & Cremonese, 1994) was conducted on the Apache Longbow to determine cost savings realized from an application of MANPRINT to 80 product improvement designs. Besides the operational performance improvements, HFI contributed directly to at least a $16.8-million cost avoidance in operations and support, based on the Longbow redesign.

The Fox reconnaissance vehicle (XM93A1 NBC) demonstrates quantitative benefits and lessons learned from HFI applications on a non-major system in an operational test environment. Distinct HFI methodologies were used in this example and cost savings were realized immediately in the program. HFI methodologies for human figure modeling (mannequin) and hardware versus manpower (HARDMAN) III were applied by the Human Research and Engineering Directorate (HRED) of the U.S. Army Research Laboratory (ARL) to Fox rapidly and effectively in such a way that between $2 and $4 million in operational testing (contract and schedule) costs were avoided, effectively saving the program from cancellation. Since smaller programs are generally unaware of the benefits that HFI can provide, Fox is an excellent example to demonstrate that HFI advantages are not limited to new or existing major programs.

Crusader was selected for the report for a somewhat different reason. There is no documentation of the direct quantitative cost benefits of HFI to Crusader as in the three examples given. However, a recent concept evaluation program (CEP) conducted by TSM Cannon and ARL illustrates the critical role played by HFI technologies in conducting realistic battlefield scenarios in war games. Further, the Crusader battle lab experiments demonstrate that the use of HFI allows the creation of (a) a flexible distributed interactive simulation (DIS) test environment; (b) a simulation facility for combining training and testing functions; and (c) a methodology for evaluating soldier and system performance in a DIS environment. This extension of HFI methodology into operational decision-making areas demonstrates the importance of HFI as an

inherent part of testing and evaluating any system that will play a role in the digital battlefield of the future.

In the following discussion, attention is given to the effects of HFI in five major areas:

- The acquisition process
- System design and development
- Operational performance and testing
- Cost avoidance
- Safety benefits

CASE 1: COMANCHE

Background

The Army's Comanche is being developed as a lightweight, twin engine helicopter capable of performing armed reconnaissance and light attack missions. From the beginning, the Comanche has had a number of ambitious goals including

1. Push the state of the art by incorporating the latest aircraft technologies to enhance its performance in complex missions in a wide range of environments including night, nap of the earth, and adverse weather conditions.

2. Be one of the most supportable aircraft in the world.
3. Have increased safety measures for air crew survivability.
4. Achieve the added performance features without unduly increasing operational and support costs over that to maintain the current reconnaissance and light attack helicopter fleet.

It was realized by Army leadership that the challenges to meet the ambitious performance goals would require major changes in the acquisition and design processes. This was especially true regarding the emphasis to be placed on the human design component. Through the MANPRINT and HSI approach, HFI methodology was inserted in the earliest stages of requirements development and carried throughout each subsequent stage of the acquisition process. The Comanche report (Minninger et al., 1995) that documented the results of the human-centered approach was based on a 5-year record-keeping effort by both the winning contractor, Boeing-Sikorsky, and the Comanche Program Office. These results are without question some of the most impressive ever reported for a major weapon system acquisition (see Figure 1).

MANPRINT
Impact on Comanche

- **Improved Army acquisition process (e.g., Source Selection, TSM-Forward)**
- **Drove human-centered design - 500 design improvements**
- **Maximization of total system performance (pilot workload, maintenance ease, personnel safety)**
- **Cost Avoidance > $3.29B**
- **Avoids 91 fatalities, 116 disabling injuries**

Figure 1. MANPRINT impact on Comanche.

Other new initiatives (e.g., total quality management, concurrent engineering, integrated logistics support) created an environment for Comanche design and development, which were compatible with the human-centered approach. As a direct result of these efforts and changes in the acquisition process, more than 500 design improvements were approved to aid in system performance and logistics. These improvements were accomplished while demonstrating projected cost avoidance of $3.29 billion in manpower, personnel, training, and safety. Additionally, 91 fatalities and 116 disabling injuries were avoided.

Acquisition Process

The Comanche philosophy has been to focus on maximizing the Army aviation's battlefield influence by fielding a totally integrated weapon system with the appropriate mix of quality soldiers, hardware, and software. To achieve a "total system," as opposed to an "equipment-oriented" perspective, HFI principles were applied to the design and development of the Comanche aircraft. Inherent in such a philosophy of a total system's view is the crucial concept that the soldier is not added to the system, but that the soldier (whether air crew member, maintainer, or support personnel) is an integral part of the system.

The total systems philosophy required a new organization and management process that horizontally integrated the widely disparate MANPRINT, supportability, engineering, and cost disciplines. This horizontal integration of discreet development processes encouraged the disintegration of traditionally organizational barriers and facilitated interaction outside those barriers. In this way, effective design decisions could be made, which reflected all participating disciplines. The Comanche process predated the recently introduced concepts such as integrated process teams (IPT). This, of course, is the intention of the modern acquisition improvement concepts with IPT. The Comanche program has already demonstrated the IPT is effective but importantly for this report also emphasizes that the IPT would not have been effective had MANPRINT not been provided such a prominent status. In fact, for integration across disciplines, only the focus on the soldier permitted a true integrating focus.

The Comanche report highlights a number of management initiatives driven by HFI principles:

- Concept exploration and advanced modeling and simulations
- Concurrent engineering (integrated concept teams and integrated process teams)
- Source selection and MANPRINT
- Continuous acquisition and life cycle support (CALS)
- Comanche supportability initiative
- HFI quantitative trade analyses
- Training and Doctrine Command (TRADOC) system manager (TSM)-forward
- Pilot-vehicle interface mechanization specification

A few of these initiatives are described in this report as examples of the major influence that HFI methodologies had upon the Comanche acquisition process.

Concept Exploration and Advanced Modeling and Simulations

Long before the current Comanche program and during the concept exploration stages for the light helicopter experimental (LHX) (precursor of Comanche) program, advanced modeling and simulation activities were initiated through the advanced rotorcraft technology integration (ARTI) program. Pilot workload issues were considered early as a potential limiting factor of the LHX concept. Advanced simulation was employed in the study of pilot tasks using a wide field of view (FOV) helmet-mounted display (HMD), electro-optical systems, and very high speed integrated circuit (VHSIC) electronics. Human-driven analyses, computer simulations, and physical mock-ups were used to improve and assess the effectiveness of the

aircraft's total system performance. At the time, an important manpower issue was a one-versus two-pilot cockpit, and a critical training issue was simulation fidelity.

A MANPRINT analysis of pilot tasks was used to reduce the risk of the LHX developmental program and prove the feasibility of a single pilot scout or attack helicopter as well as general cockpit and architecture design. To meet the single-pilot objective, the state of the art had to be pushed to the maximum. As an absolute minimum, not only did human engineering requirements have to be incorporated into the aircraft architecture, but the majority of in-flight functional activities had to be automated. The automated features included detection, recognition, identification, and prioritization of targets; management of non-critical flight control functions; navigation; automatic location reporting; and mission and flight status. The technology thrust was to provide this critical real-time information within the pilot's FOV, looking outside the aircraft, so that he or she would not have to look down at the control panel. HFI research showed this was feasible by using sophisticated "heads-up and eyes-out" displays integrated into the pilot's helmet. The HMD also could provide forward-looking infrared (FLIR) imagery for target identification and acquisition. The cockpit design also incorporated two integrated multi-purpose displays mounted in the control panel.

As part of the modeling and simulation efforts, performance and subjective mental workload data were obtained from HFI real-time simulations of flight dynamics, external visual scenes, and responses of mission equipment packages. Flight tests in modified aircraft verified the HFI simulations in which a pilot could use helmet-mounted and multi-purpose displays while performing normal flight tasks.

Source Selection

The source selection evaluation criteria used in the Comanche program represented a radical departure from past acquisition programs that had MANPRINT domains buried under other major areas which were not integrated. Figure 2 shows that MANPRINT (including training) was made a separate evaluation area with the same weight as reliability, availability, maintainability-integrated logistics support (RAM-ILS). MANPRINT and ILS were combined under the same review team so that MANPRINT-ILS had the same weight (35%) as technical. This was made known to industry during the request for proposal (RFP) stage, showing the Government was serious about its commitment to the soldier. With such weighting factors, a contract could be won or lost, based on HFI understanding and proposed approach using HFI methodology.

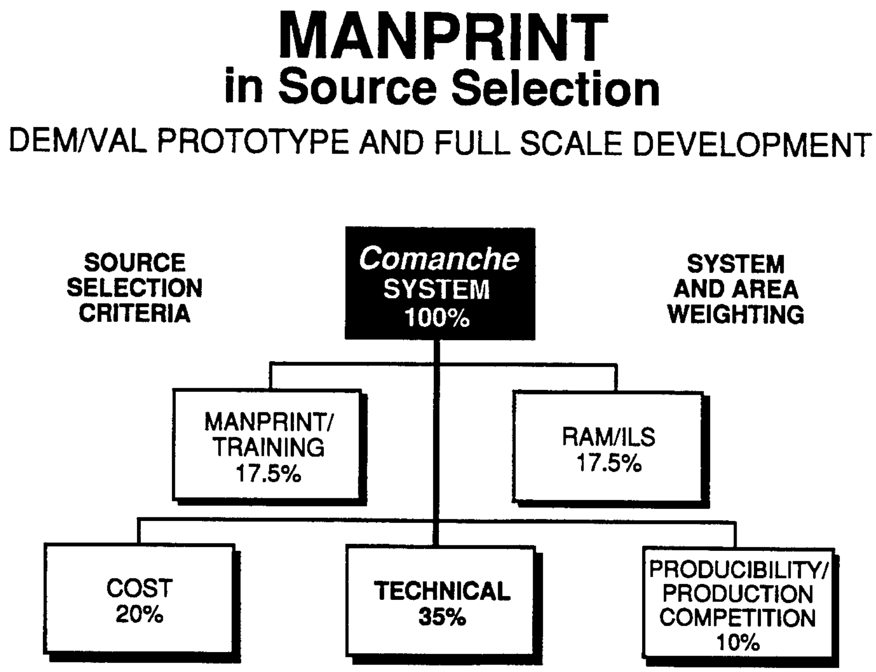


Figure 2. MANPRINT in source selection.

As it happens, even more important to effective design (once industry was convinced that the Government was serious about HFI, which was communicated by showing the major area emphasis) was the additional emphasis on MANPRINT within the technical evaluation criteria (see Figure 3). A very high percentage of the technical evaluation areas was also evaluated as having either strong or moderate MANPRINT implications.

Contractors were required to commit contractually to the achievement of MANPRINT, supportability, system performance goals, and the overall affordability of the Comanche program. MANPRINT objectives (and HFI methodologies that demonstrated feasibility) tended to ease the overall manpower requirements for the system and to make more efficient use of available projected manpower than had been done in the past. Because of the unique emphasis in source selection on human-centered design, MANPRINT HFI requirements were clearly communicated to the contractor. The contract statement of work (SOW) required the contractor to seek ways to incorporate HFI principles into the operation, support, and maintenance of the aircraft. By adopting HFI objectives as an inherent part of engineering design and development, the contractor was able to integrate soldier capabilities and limitations into the design with an affordable investment.

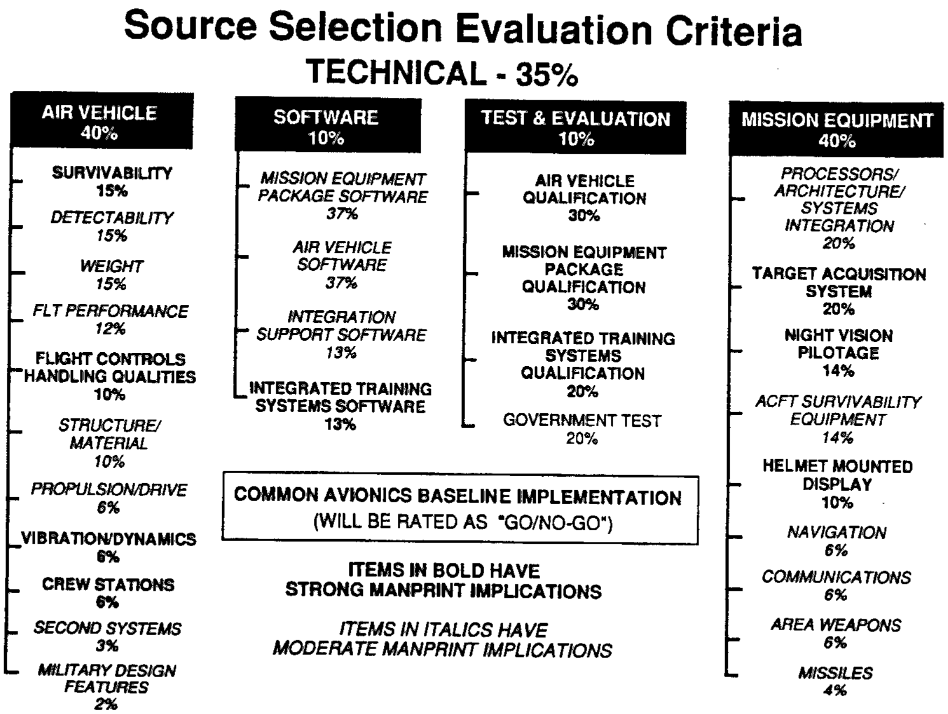


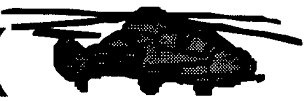
Figure 3. Source selection evaluation criteria.

HFI Quantitative Trade Analysis

During the concept exploration phase, a HARDMAN compatibility methodology (HCM) study was conducted to provide early estimates of manpower, personnel, and training (MPT) requirements, and associated training costs for a family of light helicopters, compared to predecessor systems. The HARDMAN results supported the light helicopter concept as vastly superior for MPT affordability.

An HFI tool, crew workload model, employed by the Systems Laboratory, Army Research Institute (ARI) demonstrated that without the automation planned for LHX, both one- and two-crew cockpit positions were overloaded an excessive number of times for the missions intended (see Figure 4). The missions could not be accomplished. However, even with automation, a one-person crew was overloaded in ten critical events. Only a two-person crew model with automation predicted no overloads for the LHX missions. The decision to adopt a two-seat design was therefore based on HFI analysis for superior mission performance. This was an important decision, because more maintenance personnel were required as well as more flight crews. A manpower analysis showed that the two-seat configuration would require 12%

more maintenance support than the single-seat version because of the additional cockpit equipment.

LHX 

■ **CREW WORKLOAD MODEL**

	OVERLOADS	
	ONE CREW	TWO CREW
NO AUTOMATION	263	43
AUTOMATION	10	0

■ **MANCAP MODEL**
(MANPOWER CAPABILITY)
(LIGHT INFANTRY DIVISION)

UNIT DESIGN	MANPOWER RQMT
AOE	416
LHX	313

Figure 4. LHX: automation versus no automation.

Altogether, however, a major net reduction of manpower, personnel, and training was projected for the Army. The manpower capabilities (MANCAP) model (one of nine HARDMAN III modules) was used to predict about a 25% reduction in manpower requirements (primarily maintenance) in the light infantry division with the introduction of LHX. As manpower requirements became fewer, so did personnel requirements. For example, HFI analysis showed that it would be possible to consolidate maintenance-related military occupational specialties (MOS) from 13 to 4. Still another finding was that the reductions in manpower and numbers of MOS allowed the manpower and personnel training resource requirements to be reduced an average of 27% to 39%, compared to predecessor aircraft.

While showing that the overall reductions in MPT requirement were important, still other uses of the HFI MPT technology were demonstrated, which illustrated the complexity of MPT trade-offs. In maintenance manpower, for example, depot maintenance increased 16% for the two-level maintenance concept. (This increase was partially offset by an estimated 6% reduction in manpower because of improvements in RAM). Further complexities were revealed for actual operations. While the overall light helicopter manpower and personnel were less, distribution of personnel was critical since workload requirement could be expected to increase at the unit level. The increases in unit workload were attributable to increases in operational

tempos of the aircraft within the units operating the light helicopter, compared to the aircraft it would replace.

TRADOC System Manager (TSM)-Forward

Before the selection of the contractor team to complete development of the Comanche, the Army provided teams of TRADOC soldiers to support the contractors. These teams were composed of aviators and maintenance personnel selected for their experience and ability to communicate "user" information to the contractors during the design phase. Figure 5 illustrates that with a typical contractor technical test (CTT), a design proposal would not expect peak user involvement until full scale development, a full 3-1/2 years later than the TSM-forward concept. Following selection of the prime contractor, a team of soldiers was provided to the contractors on site as an extension of the Comanche TSM, known as the TSM-forward. The TSM-forward was a unique concept in that it was neither a part of the Defense Plant Representative Office (DRPO) nor part of the Program Manager's Office (PMO). The objectives of the TSM-forward were to address and prioritize user operational and MANPRINT concerns during the demonstration and validation (DEM-VAL) prototype and subsequent engineering and manufacturing development (EMD) phases. The presence of the TSM-forward in the contractor's facility allowed user issues and concerns to be identified in a timely manner. As an example, TSM-forward activities with the product development teams reduced the time period to effect design changes between contractor and Government. In one instance, a rotor design change that would routinely have taken 12 months for contractor-Government approval was completed in 30 days.

System Design Improvements

The Comanche aircraft has been designed to be the most sophisticated helicopter ever built. It incorporates state-of-the-art technology throughout every component and subsystem of its design. Apart from those disciplines advancing helicopter technology itself, HFI is one of the most important disciplines contributing toward making the Comanche system a highly capable, operable, and supportable weapon system. Figure 6 illustrates several of the design features most notably influenced by the MANPRINT and HSI programs.

The following discussion addresses only a few of significant design and architectural improvements related to HFI influence selected from the Boeing-Sikorsky Lessons Learned Guidebook. Boeing-Sikorsky identified 500 design improvements directly related to MANPRINT.

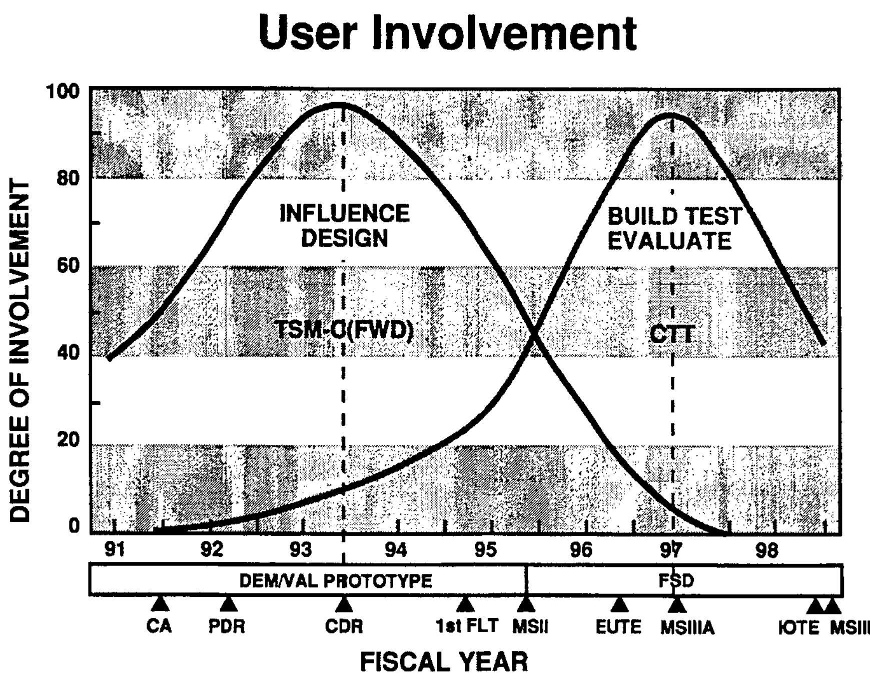


Figure 5. User involvement.

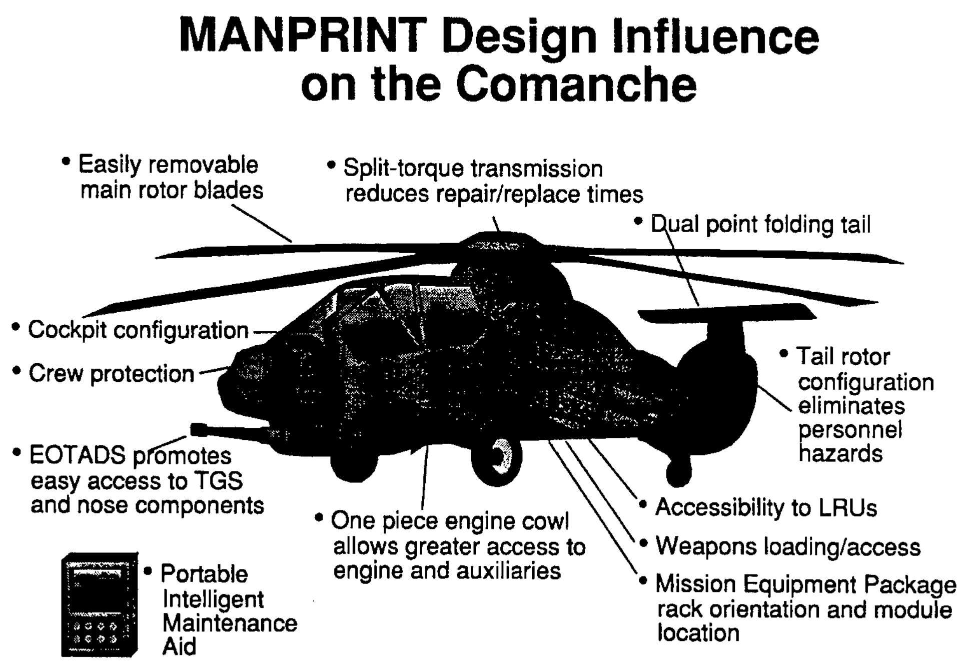


Figure 6. MANPRINT design influence on the Comanche.

Crew Station Design

Early simulations and modeling, lessons learned, and user inputs allowed the cockpit to be designed from the pilot outward. The objective of the crew station design process was to blend the airframe, computers, sensors, and crew into a low workload, low error rate, high situation awareness, quick reaction cockpit. The Comanche human factors engineering group used the Army's task analysis workload (TAWL) methodology to perform analyses of the operator tasks. As a result of the TAWL analyses, the following crew station design objectives were met:

- Reduce the number of sequential tasks required to perform mission functions.
- Ensure that human performance demands of design do not exceed human performance capabilities.
- Ensure that task performance times are acceptable for the mission.
- Ensure that the controls and displays provide adequate interface information to accomplish mission tasks.

More specifically, the TAWL and TAWL operator simulation system (TOSS) assisted the design team in simultaneously combining critical target acquisition and attack data with critical flight control data. This target, attack, and flight control information can be displayed to the air crew through the tactical situation display (TSD) mounted on the display panel (see Figure 7) or the helmet-integrated display sighting system (HIDSS) attached to the crew member's helmet.

A central feature of the crew station design allows the air crew to set priorities for information criticality at specific points during missions. Overall, the sequence of tasks required to perform mission functions was drastically reduced. For example, as shown in Figure 8, a sequence for target reporting that previously required 34 procedural steps in the OH-58D was reduced to only 5 in the Comanche.

Rotor Blade Design

The Comanche Pentaflex blade design provides an excellent lesson learned for industry about the unexpected benefits that can accrue when HFI principles are adopted. The Boeing-Sikorsky design team had originally considered a rotor blade design that met Government specifications but about which MANPRINT and ILS contractor personnel had raised maintainability and transportability concerns. Because the team was still competing with McDonnell Douglas, it was reluctant to expend extra design resources when they were not required.

Cockpit Designed for the Missions

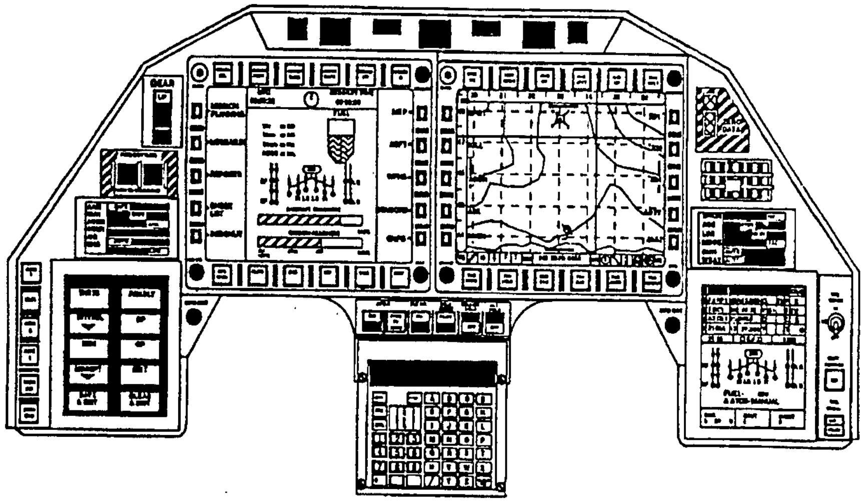


Figure 7. Cockpit designed for the missions.

Multiple Sequential Action Reduction

In the Comanche

1. PRESS "TSD WNDW"
2. SLEW CURSOR TO DESIRED TARGET
3. HOOK WITH SLEW CONTROLLER
4. PRESS "SPOT"
5. PRESS "SEND" (EITHER URGENT OR ROUTINE)

Total Procedure Steps = 5

In the OH-58D

1. PRESS ATHS KEY
2. PRESS REPORTS
3. PRESS SPOT
4. PRESS TGT LINE SELECT
5. ENTER "3" ON KEYBOARD
7. PRESS ACTIVITY
8. PRESS MOVEMENT LINE SELECT
9. ENTER "1" ON KEYBOARD
10. ENTER "5" ON KEYBOARD
11. ENTER "ENTER" ON KEYBOARD
12. ENTER "1" ON KEYBOARD
13. ENTER "3" ON KEYBOARD
14. ENTER "ENTER" ON KEYBOARD
15. PRESS ACTIVITY LINE SELECT
16. PRESS MISSION LINE SELECT
17. PRESS "SEND"
18. REPEAT STEPS 1-17 TO REPORT ON LIGHT WHEELED VEHICLES

Total Procedure Steps = 34

SITUATION:
Crew has bobbed up and sighted an advance guard of a motorized rifle BN. They see three BMPs and four light wheeled vehicles. They are to report this immediately.

ASSUMPTIONS:
1. **Comparison of Comanche procedural steps to OH-58D with ATHS**
2. **Target has been identified by the crew via the TIS on the OH-58D and TAS on the Comanche**

Figure 8. Multiple sequential action reduction.

Nevertheless, MANPRINT and ILS persevered and the team decided to develop a new modular design that was easier to maintain, reduced the potential for installation error, and eliminated close fit tolerance for transportability (see Figure 9). The amount of additional effort for the MANPRINT analyses, test and evaluation, and drawing change was 395 man-hours, probably costing the contractor less than $50,000. However, when a life cycle cost analysis was conducted later, approximate $150 million was calculated as avoided because of this design improvement. These savings would come primarily from manpower requirements reductions in skill and numbers because of easier and less maintenance of the rotor blades and reductions in transportability times.

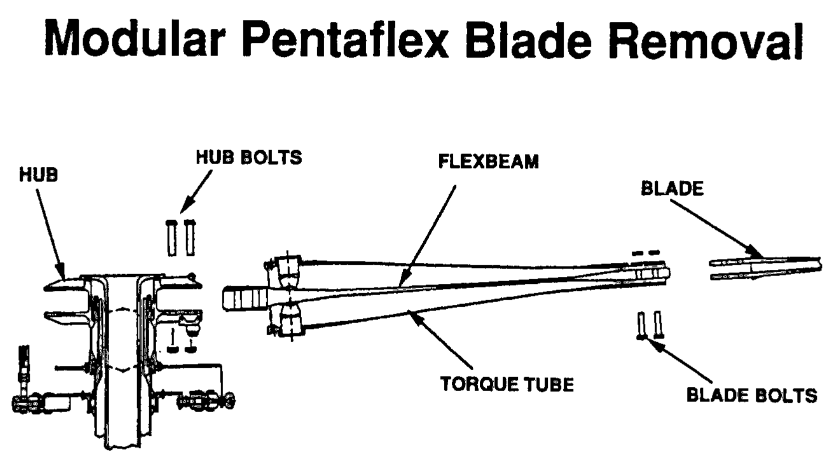


Figure 9. Modular Pentaflex blade removal.

T-800 Engine

The T-800 engine was the first Army development program in which the MANPRINT process played a major role. MANPRINT's visibility allowed ILS and RAM programs to be more effective in influencing the design process and also provided for the integration of soldier capabilities and limitations with system development. During the design and development process, widely varying HFI tools (analyses, models, mock-ups) were used to improve, validate, and assess the effectiveness of the T-800 system. Benefits were extensive in the areas of manpower, personnel, and training as a result of Government limitations in the RFP stating the design was to have no increase in skills or manpower numbers. As shown in Figure 10, the engine had an extensive number of improvements, based on the MPT limitations. The modular design eliminated the need for scheduled overhaul. The elimination of the need for torque wrenches reduced both the number of tools required and the level of maintenance. In designing the engine to be more maintainable, it had become more reliable as well. The increased reliability and maintainability not only decreased the maintenance per operating hour but reduced

overall training burden by as much as 40% for comparable engines of the current aircraft fleet. Some of the other many benefits to the T-800 from HFI have been documented by Howington and Goldthwaite (1989), Booher (1990), and in a 1993 case study held in the Army MANPRINT Headquarters Office (DAPE-MR).

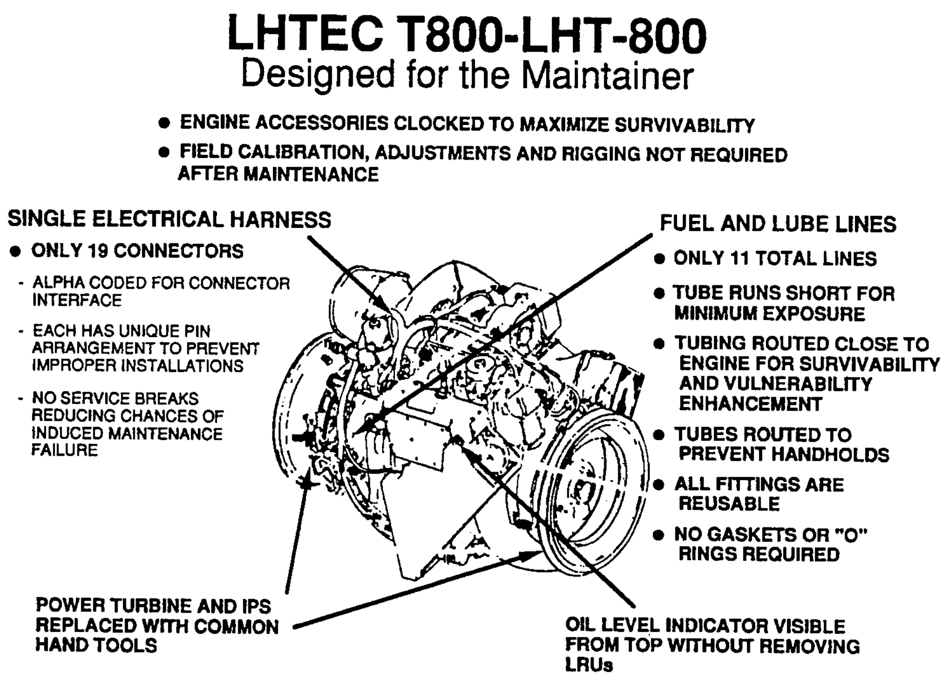


Figure 10. LHTEC T800-LHT-800.

Box Structure Design

Driven by MANPRINT access requirements of helicopter on-board components, especially in a field environment, an entirely new load-bearing structure was designed for Comanche. The new box structure is a graphite-epoxy composite material which allows more than 50% of the exterior skin to have access doors and panels (see Figure 11). Mission equipment packages (MEPs) are accessible for maintenance and inspection in a field environment. Several of the access panels open at convenient locations to serve as work platforms, thus eliminating need for separate ladders or special work platforms. The design and placement of aircraft components, built-in access doors, and convenient work platforms make it possible for fast turnaround of maintenance and loading tasks. By partitioning the electro-optical target acquisition and designation system (EOTADS) sensor functions, a 40% life cycle cost avoidance in supply stockage is projected. Loading of the 20-mm gun can be accomplished by one person

from the side of the aircraft. The feature of adjustable weapon bay doors allows missile ordnance loading in less than 13 minutes with only two personnel.

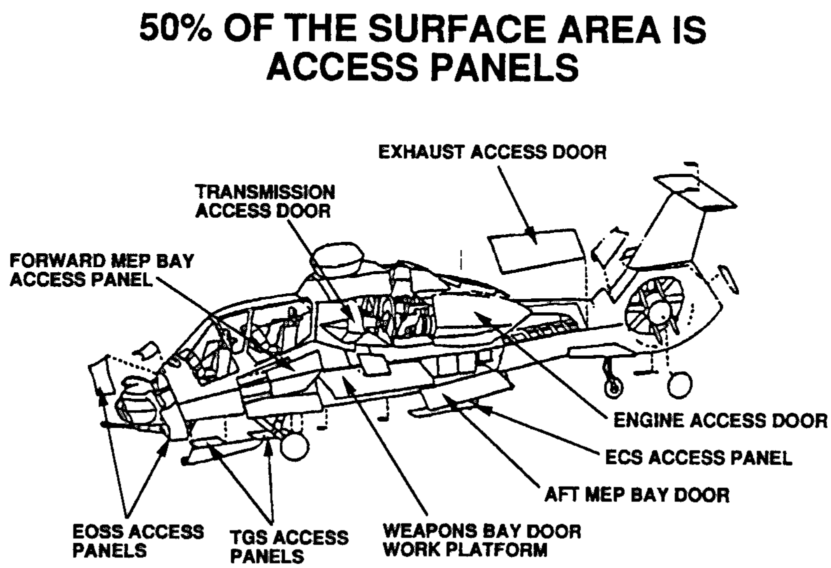


Figure 11. Surface area access panels.

Tail Rotor

The Comanche "fan-in-fin" composite tail (FANTAIL) is a protected, eight-bladed, rigid rotor system designed to continue safe flight after the loss of any FANTAIL blade (see Figure 12). The FANTAIL anti-torque system provides improved aircraft maneuverability, and each blade is individually field replaceable through an access panel mounted within the fan duct. The protected FANTAIL improves safety for personnel during ground operations and to the airframe and air crew during nap-of-the-earth flight and other flight operations.

During early design, the technical advantages of the FANTAIL rotor for flight efficiency were recognized. The crew and aircraft survivability were also increased with the new FANTAIL design. During the trade-off analysis, the FANTAIL design was found to be eight times safer than the traditional rotor design. HFI safety analysis played a significant role in that analysis. Additionally, a shroud was added to protect ground crew from the tail rotor. It was known that in the past, unprotected tail rotors have contributed to many avoidable accidents. This was significant for HFI design influence because the shroud added extra weight not planned for originally. However, because of MANPRINT bringing together the voice of safety, maintenance, and flight operations, weight offsets in other areas allowed the increased weight for ground personnel safety.

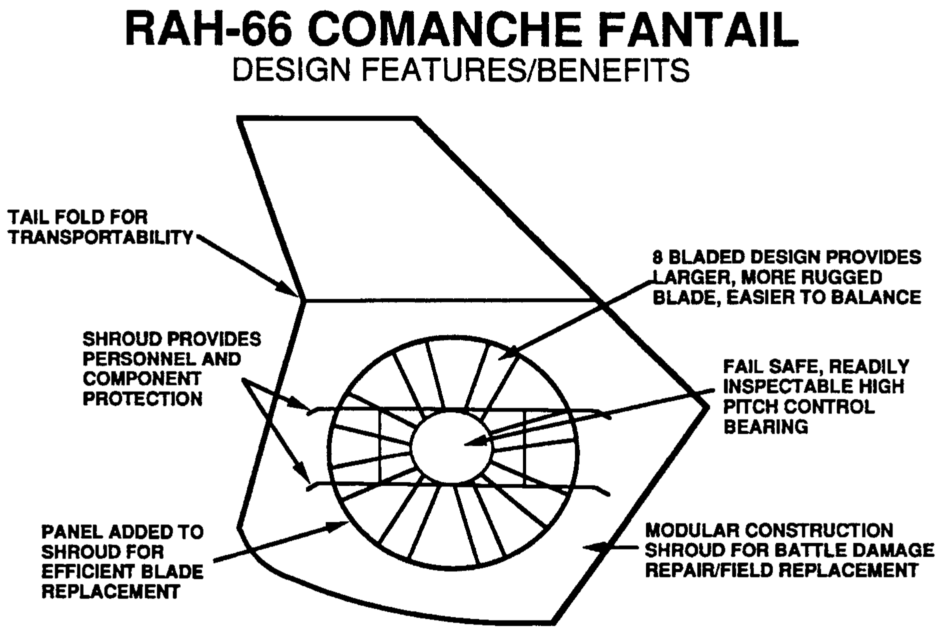


Figure 12. RAH-66 Comanche fantail.

Comanche Cost Avoidance

Minninger, Skonieczny, and Yawn (1995) document their assessment of cost avoidance attributable to MANPRINT-HSI. Although MANPRINT attributes were closely linked to other disciplines such as ILS and RAM, it was not always possible for the analysis to identify those savings directly attributable to HFI. However, the cost avoidance documented in that report was entirely in the MANPRINT domains of manpower, personnel, training, and safety. It was also recognized that the MANPRINT approach, which focused on the soldier and communication to industry through its acquisition process, significantly changed the design process for the contractor. The cost-avoidance assumptions and rationale are provided in Figure 13. Details of the cost avoidance estimate rationale are provided in Appendix B of the Minninger et al. (1995) report.

The Army manpower cost system (AMCOS) model was used to quantify cost avoidance attributable to the contributing factors of manpower, personnel, and training which follow from such items as reduction of number of MOSs, reduction in maintenance levels, and reduced training requirements. The contributing factors for Comanche were compared to the predecessor systems OH-58 and AH-1 being replaced with Comanche. To standardize comparisons, identical

operational tempos were used for Comanche and the predecessor systems. It is important to recognize that the systems being replaced would not only require the higher manpower, personnel, and training costs but would also be unable to perform many of the new capabilities provided by Comanche. Other analyses such as those just described in determining fielding requirements showing a 25% reduction in overall maintenance requirements are not reflected here because those analyses consider the full manpower, personnel, and training needed to fully employ Comanche's capabilities.

Comanche

Cost Avoidance Assumptions and Rationale

- Cost Avoidance is used in lieu of Cost Savings; OH-58A/Cs and AH-1s are being replaced by a system with a quantum increase in capabilities.
- 1993 Version of the Army Manpower Cost System (AMCOS) model was used for all Manpower, Personnel, and Training cost estimates.
- Identical operational tempos were used to standardize comparisons.
- Maintenance manhour per flight hour values were taken from AR 570-2 for predecessor aircraft and Comanche RAM requirements.
- Safety and Soldier Survivability estimates were based on CYs 84-93 Safety Center mishap data and specific Comanche design improvements over the Kiowa and Cobra aircraft being replaced.

Figure 13. Comanche cost-avoidance assumptions and rationale.

Safety and soldier survivability estimates were based on safety center mishap data and consideration of those specific Comanche design improvements aimed at eliminating design deficiencies of the Kiowa and Cobra aircraft, which safety analyses show could have been prevented by design changes.

The cost avoidance figures attributable to HFI are broken down into three categories (see Figure 14). Manpower shows that 32% of the predecessor manpower costs are avoided in Comanche, which equals $2.67 billion. Personnel and training together avoid 33% of predecessor personnel and training costs or $440 million, and safety, health hazards, and soldier survivability costs avoided equate to $180 million. (Note. The percentages in Figure 16 are not additive. Each percentage is calculated only within its category rather than as a percentage of total cost

avoidance, since within category savings is a more meaningful percentage.) *The total Comanche cost avoidance because of human factors integration is $3.29 billion.*

Human Factors Integration Cost Avoidance

Impact Areas	% of Cost Avoided	$ Avoidance
Manpower	**32.1%**	**$ 2.67 B**
Personnel/Training	**33.1%**	**$ 0.44 B**
Safety/Health Hazards/ Survivability	**14.5%**	**$ 0.18 B**
	Comanche Cost Avoidance	**$ 3.29 B**

Figure 14. Human factors integration cost avoidance.

The investment currently being made for MANPRINT and HFI domains during the prototype development phase is shown in Figure 15. Over the next 10 years, MANPRINT costs are planned to be approximately $27 million. *The ratio of cost avoidance to cost is 122, or 12,200%.* This is a staggering return to the Army from HFI influence on design. (Note. There were also the design stage costs, which were relatively small, approximately 4% of the Comanche budget. ILS also received about 4% of the design budget. Combined MANPRINT-ILS was no more than 8% of the design costs. This would, however, raise the total MANPRINT costs, but even if the design costs were computed, the cost avoidance would probably still be 40 times more than the investment [see Table 2]. Also, on the return side, savings in reductions of engineering change proposals can be expected but were not calculated in this exercise.)

It is important to note that the investment in HFI was not made primarily to avoid costs. The costs avoided were secondary. HFI is primarily a discipline to assure that (a) adequate numbers of personnel with the right skill levels with the proper training are accounted for in the design; (b) the system being designed will adequately perform the missions it is being designed to do, by designing all soldier requirements into the system; and (c) the system will perform safely with a minimum potential for health hazards or soldier casualties. These considerations have always been funded in major defense programs. In fact, if Comanche had been procured in the same way as past programs, one could have expected nearly the same amount of costs for the MANPRINT domains, if each domain were funded separately. The primary difference was the

integration of the domains applied systematically as an inherent part of the Comanche design philosophy. Of course, those programs that do not invest in HFI would not expect to see either performance or cost-avoidance benefits. *The two primary cost benefits lessons learned from Comanche are (a) resources not only need to be invested in HFI but must be properly applied, and (b) the MANPRINT procedures applied on the Comanche provide the proper manner of investment.*

Comanche MANPRINT

Development Costs $(k) FY97-FY06

MANPRINT Management	**5,184**
Human Factors	**6,087**
MPT Analysis	**3,459**
System Safety/Health Hazards	**11,313**
MANPRINT Evaluation	**850.5**
	26,893.5

Figure 15. Comanche MANPRINT development costs.

Comanche Fatality and Disabling Injury Avoidance

It is projected that use of the Comanche rather than the OH-58 A/C and AH-1F aircraft will avoid 91 soldiers' deaths over a period of 20 years. Similarly, use of the Comanche will avoid at least 116 disabling injuries (see Figure 16). Nine years of accident and incident data reported to the U.S. Army Safety Center were reviewed for events causing personnel deaths and disabling injuries in the older aircraft. During this period, 26 and 39 fatalities (i.e., fatalities that safety analysis showed could have been prevented by improved design) were related to the AH-1 and OH-58, respectively. Also during the 9-year period, 23 and 63 disabling injuries were related to the AH-1 and OH-58, respectively. Some of the incident types and corresponding design improvements are listed in Table 2.

Safety
Life Cycle Death/Injury Avoidance

Twenty year Life Cycle Costs avoided compared to the aircraft being replaced

Aircraft Type	Disabling Injuries Avoided	Deaths Avoided
AH - 1 Cobra	29.1	37.1
OH - 58 A/C Kiowa	87.8	54.1
Total	116.9	91.2

Figure 16. Safety-life cycle death injury avoidance.

Table 2

Comanche Incident Types and Design Improvements

Incident type	Design improvements
Aircraft collisions	Improved outside visibility Two pilots for all current missions
Aircraft crash	Improved night vision capabilities Improved situational awareness Ground proximity warning system Improved airframe crash survivability
In-flight breakup	Strengthened composite airframe Improved rotor system prevents mast bumping
Engine failure	Monitoring systems warn of impending failure Engines can operate 20 minutes after loss of oil
Loss of tail rotor effectiveness	FANTAIL system does not limit flight envelope FANTAIL can operate after loss of a blade
Ground accidents	Work platforms built into the airframe FANTAIL shrouded with added safety bars

CASE 2: APACHE

In 1994, the Apache contractor McDonnell Douglas Helicopter Systems conducted a study of MANPRINT cost savings on the Longbow Apache. The study covered the four previous years in which the Longbow Apache MANPRINT team participated in the EMD issues that were raised throughout the concurrent engineering process but not documented. However, a number of issues that were not readily resolved were labeled as problems, issues, and concerns (PICs) (see Figure 17). An item could become a PIC via recommendation by the Army for failure to comply with documented company or military standard or by continual refusal by a designer to comply with user-friendly design practices without acceptable rationale.

PIC Example - Seat Stroke Interference

- **Apache Crash Survivable Seats "stroke" during crash**
- **Original Design had brackets which interfered with stroke**
- **MANPRINT redesign: depths of left control panels reduced & redesign brackets**
- **Cost avoidance for Class A mishap $2,619k (did not include loss of crew productivity or incalculable loss of aviator's life)**
- **Non-recurring cost $10k**

Figure 17. Apache Longbow PIC example.

HFI Cost Savings Study

Irving, Hampton, and Cremonese (1994) report that 161 PICs had been documented at the time of their study. At the time, 86 had been resolved, of which, 80 were judged capable of objective analysis for determining quantifiable cost savings or cost avoidance for their customers. The study team analyzed 5 of the 80 resolved PICs that they felt represented a wide range of HFI impacts on the Apache. For the five PICs alone, the team found a $16.8 million cost avoidance. They concluded that this represents only a small fraction of the total cost savings and avoidance to be realized by the Army throughout the Longbow Apache life cycle. The investment in MANPRINT for the entire full scale development is $2.7 million (see Figure 18). Allowing for implementation costs, the five PICs alone will provide a return 5 times (500%) the investment into

HFI. If one were to extrapolate to all 80 PICs, however, the return would amount to more than 20 times the same investment--not as high as the Comanche, either in total dollars saved or return on investment, but a number well worth the investment.

Contractor MANPRINT Cost Savings Study

- **Problems, Issue, and Concerns (PICs) Methodology**
- **80 MANPRINT PICs Identified and Corrected**
- **5 High Payoff PICs Analyzed**
- **$16.8 million Cost Avoidance (5 PICs)**
- **$2.7 million Investment (80 PICs)**

Figure 18. Apache Longbow contractor MANPRINT cost savings study.

HFI Design Influence

The five items selected for HFI analysis were (a) seat stroke interference, (b) extended forward avionics bay (EFAB) contour, (c) rotor head access, (d) tail rotor rigging pin, and (e) data rate adapter mounting. The seat stroke interference and the EFAB contour related to design deficiencies that could have caused loss of life and aircraft if they had not been resolved. The remaining three were concerned with maintainer access to components and fasteners and the time and costs involved with difficulties in access.

The calculations were based on a fleet of 800 aircraft, with each flying 240 hours per year over a life cycle of 20 years. Failure and access rates were based on a mean time between removal (MTBR) values provided in the McDonnell Douglas Systems engineering RAM database. The manpower cost was assumed to be $7.00 per direct maintenance man-hour.

Seat Stroke Interference

The Apache is equipped with crash-survivable seats that "stroke" (collapse) during a crash to absorb energy in order to reduce injuries of crew members. The original design for Longbow Apache included new brackets for the left consoles of both crew stations that reduced the clearance on the left side of the seats and interfered with the stroke. As a result of HFI, the depths of the control panels on the left side were reduced and the Apache Longbow

brackets were redesigned to allow the seats to stroke identically to those in the fielded Apache (AH-64A).

Using historical data for Class A mishaps, the cost avoidance for this design correction led to an estimated savings of $2,610,000, not including the loss of crew productivity or the incalculable loss of aviators' lives. This deficiency was resolved by making minor changes in one control panel and a single bracket at a non-recurring cost of less than $10,000.

Rotor Head Access

To access the rotor head, Apache maintainers habitually stand on the engines, the infrared jammer support, and catwalk door hinges. These practices have led to injury and maintenance-induced damage in AH-64A Apaches. A review of lessons learned from the AH-64A brought this issue into the MANPRINT analysis process. The analysis found the Longbow Apache environmental control system (ECS) structure would be exposed to damage when used by mechanics as steps and handholds.

As a result of HFI recommendations, the ECS support structures were redesigned to incorporate a work platform. The new platform not only provides maintenance access to the rotor head components but also protects ECS components. The analysis of frequency of repair in the rotor head area showed that Apache maintainers might need to access the rotor head area more than 92,000 times throughout the fleet life cycle. Assuming that the expensive blower or transition duct could be damaged by maintenance personnel to the extent that it would have to be replaced 2% of the time, cost avoidance of replacement parts alone (not including aircraft down time or man-hours to make the repairs) would be about $4,577,000. The fleet implementation expense for the maintenance platform will be about $568,000, a return of 8 times the investment.

Extended Forward Avionics Bay (EFAB) Contour

The Longbow Apache avionics bays were enlarged in comparison to the predecessor system, causing designers to redesign for changes in air flow. On the right side of the aircraft, a fairing was constructed to improve air flow over the top of the wing. Unfortunately, the new design created a safety hazard. If, during flight, a foreign object were to be directed down the top of the EFAB, the object would likewise be directed toward the engine inlet and sucked into the engine. The faster the forward aircraft's air speed, the more likely the ingestion of the foreign object. If this were to occur during nap of the earth, an engine failure could result in loss of aircraft and flight crew. As a result of the HFI effort, the fairing was eliminated and replaced by a smaller fairing that diverts air and foreign objects under the wing and outboard rather than

into the engine. This hazard was resolved with a non-recurring cost of approximately $10,000, with a cost avoidance of more than $10 million.

Tail Rotor Rigging Pin

The proposed rigging of the tail rotor flight controls was difficult to access. The maintainer had to insert a pin in the flight control package below the pilot crew station's right console. Two ECS components, a fan and an evaporator, had to be removed to access the rigging pin hole. An additional maintainer MOS was required to remove ECS components. In the human factors redesign, the fan and evaporator were relocated slightly aft to allow access for the rigging pin, eliminating both the access problem and the second maintainer. For an implementation cost of $8,000, manpower costs were reduced by about $300,000.

Data Rate Adapter Mounting

Line-replaceable units (LRUs) mounted below the Longbow programmable signal processor are tightly packed. Data rate adapters (DRAs) mounted in this area with fasteners facing in board could not be removed without first removing adjacent LRUs. By fastening the DRAs to a sheet metal bracket that mounts to a shelf with fasteners facing outward, maintenance was eased. This small change costing about $4,000 will result in cost savings of more than $76,000.

Apache Return on Investment

The five PICs' costs savings were estimated to total $16.8 million over the life cycle of the Longbow Apache. This was offset by design and implementation costs of $600,000, a ratio of savings to costs of 28 times or 2800%. Another way to compute the cost benefits is to consider the entire costs of the McDonnell Douglas MANPRINT team over the full development cycle combined with estimated design and implementation costs. Extrapolating the five PICs to 80 equals 16. Assuming that the five PICs are a good representation, 16.8M x 16 = 268.8M, and 600 K x 16 = 9.6M. Combining total design change costs, 9.6M, plus MANPRINT costs, (2.7M) = 12.3M. Dividing savings by costs (268.8M ÷ 12.3M = 21.8 or 2180%). One should notice that although this is a very high ratio, it is 6 times less than that of the Comanche, and the costs to make the design changes are more than 3 times those of the Comanche MANPRINT. This is because of higher design and implementation costs for a modification, compared to an original design and the limits to design at the later stage.

CASE 3: FOX VEHICLE

The Fox vehicle is an ACAT-III development program with Congressional oversight. Its formal title is the XM93A1, nuclear, biological, and chemical reconnaissance system (NBCRS). The XM93A1 is a system improvement plan (SIP) of the M93 program. Fox is designed to move over terrain possibly having NBC contamination, pick up and analyze samples, and identify and mark contaminated areas. Fox was originally designed for operation by a crew of four.

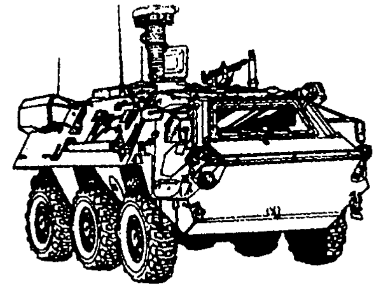
The SIP improvements include (a) reducing the crew from four men to three soldiers, (b) replacing contractor maintenance with Army logistics support (i.e., soldier), and (c) adding stand-off detection capability. From a workload perspective, it would appear that the SIP vehicle without design modification would have a serious problem with crew workload. The soldier maintenance and stand-off detection would increase the tasks that would be distributed among fewer soldiers. The test and evaluation integrated process team (T&E IPT) thought that automation would reduce the workload to acceptable levels; however, the Operational Evaluation Command (OEC) gave the Fox SIP an initial outfit test and evaluation (IOT&E) assessment of "unsuitable and ineffective." HRED of ARL was called upon by the Fox Program Manager for assistance. McMahon (1996) describes the strategy used by ARL to design a SIP + based on two different types of HFI modeling capability, a workstation human figure modeling and a HARDMAN III task network modeling (see Figure 19).

Human Figure Modeling

The original four-person crew had two positions at the front of the vehicle, one on the right side, and one at the rear. To eliminate one of the crew, a workstation design change was required to combine two positions into one. It was decided that the rearward positions could be combined into one by combining the soldier-machine interfaces. A computer-aided design (CAD) database of Fox was developed, and anthropometrically sized human figure models included in the software were used to perform the HFI analysis of each workstation (see Figure 20).

The human figure models of the rear stations showed how the old controls and displays for the seat on the right could be combined into a single, rear crew station. ARL developed a CAD database of the NBCRS workstations and used a human figure modeling tool to assist in SIP + hardware placement. The human figure model was also exercised to verify that the current SIP + design is within the FOV and reach envelope of a 5th percentile female operator. The NBCRS database can now be used to support the integration of future pre-planned technological improvements with optimized soldier-system interfaces (see Figure 21).

System Improvement Program (SIP)
for
Nuclear, Biological, & Chemical Reconnaissance System (NBCRS) - 'Fox'



Requirement

- Reduce crew to 3 soldiers
- Army logistics support
- Added stand-off detection capability

Problem

- 3-man crew SIP failed test
- $$ to re-design + $$ to Re-test > $$ remaining

Strategy

- SIP + design based on:
  - Human Figure Modeling
  - HARDMAN III task network modeling
- Test to verify model

Figure 19. System improvement program for NBCRS-Fox.

Human Figure Model of FOX Crewstations

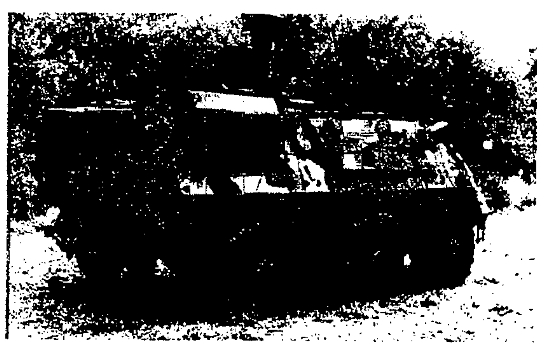


Figure 20. Human figure model of Fox crew stations.

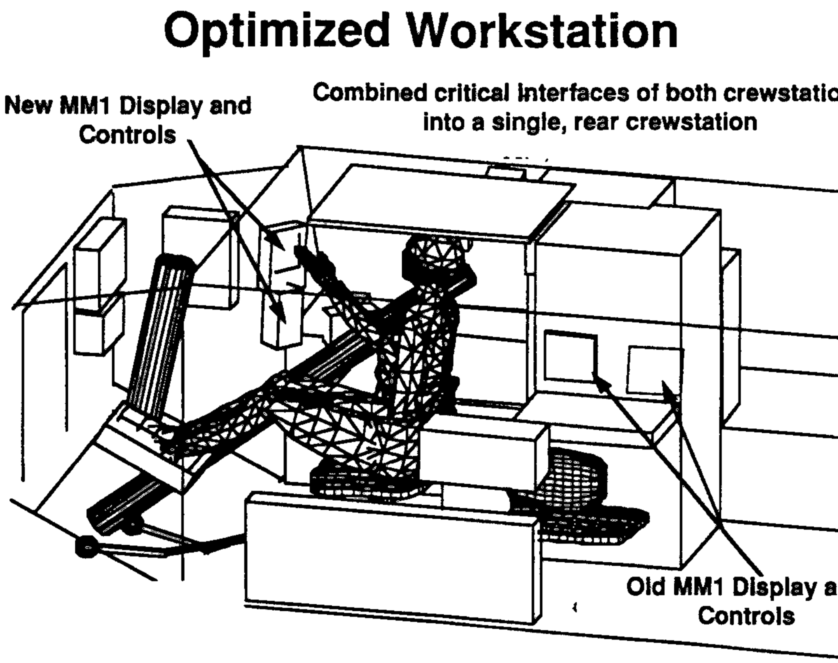


Figure 21. Optimized workstation.

HARDMAN III Task Network Modeling

The human figure modeling provided confidence that the two crew stations could be combined into one. It was still a question, however, whether the three crew members would be able to meet NBC reconnaissance mission requirements. For example, to accomplish such mission functions as movement to a starting point, taking a spectrum, and then finding the near side clean area, the rear crew member must continually interact with a spectrum monitor, a probe, and sampler wheels. The Operational T&E Command (OPTEC) was not convinced that the Fox functions could be satisfactorily accomplished during conditions of stress and fatigue over long periods of time. After failing its IOT&E, the Fox program was on the verge of being canceled because of schedule and funding limitations. To possibly save the program, a strategy was conceived that included performing human figure and HARDMAN III modeling in conjunction with a 2-week validation test.

The HARDMAN III manpower-based system evaluation aid (MAN-SEVAL) is a model that can produce performance model estimates to supplement operational assessments with modeling results as well as operational test data. By using the MAN-SEVAL model to obtain

performance estimates, the actual test was reduced to an affordable test: 4-hour missions, 8 hours a day, for only 2 or 3 weeks.

The HARDMAN III model was used to support the Fox vehicle SIP +. An example of the type of inputs used on the Fox task network exercise is shown in Figure 22. Mission definition in terms of functions and subfunctions was derived from the NBCRS mission crew drills. Performance time data came from the NBCRS IOT&E of FY 94. The workload assignments for visual, cognitive, psychomotor, and auditory tasks came from subject matter experts using McCracken-Aldrich scale values.

Fox Vehicle Modeling Support

Example of HARDMAN III Man-Seval Model Inputs

a **Mission Definition** (Functions & Subfunctions)	b **Performance** (Time Data)	c **Workload Assignment** (Visual Cognitive Psychomotor Auditory)			
PMCS Function	30.0 min.				
Power-up Hull	2.0 min.	5.0	1.2	2.2	1.0
Prepare FCD	2.3 min.	7.0	6.8	7.0	1.0
-	-	-	-	-	-
-	-	-	-	-	-

Notes:

a = Mission definition derived from NBCRS Mission Crew Drills.
b = Performance time data from NBCRS IOTE (FY 94).
c = Workload assignments from SME's using scale values.

Figure 22. Fox vehicle modeling support.

The HARDMAN model verified that the SIP + human factors modifications improved performance over the original SIP design in all mission functions. In fact, the overall mission time for SIP + showed a 12% (22 minutes) reduction from the SIP mission time (see Figure 23). It was determined that the SIP + modifications improve the soldiers' ability to interact with the monitor, probe, and sampler wheels.

Fox Cost Benefits

The Fox vehicle demonstrates a number of HFI lessons learned and quantitative cost benefits not realized before. First, as an ACAT-III program which is NDI, only relatively small modifications are possible. Fox clearly demonstrated that HFI soldier-machine interfaces and work space layouts are necessary when attempting to reduce manpower without creating excessive workload. Second, Fox demonstrates how widely varying HFI tools can be used to achieve the

program mission. The human factors interface technology helped design the optimum solution but would not have been adequate to overcome the IOT&E failure without the HARDMAN III task network modeling. On the other hand, if only network modeling had been done to the original design, little more would have been shown than that OPTEC was correct--that the workload was too excessive to conduct the mission. Finally, not only was the program saved, but it was done in a very cost-effective manner, *which the PM saw in his own budget in the near term.* The estimated cost to the PM for the HFI analyses, which were completed in 4 months, was $60,000. The overall program savings were $2 to 4 million.

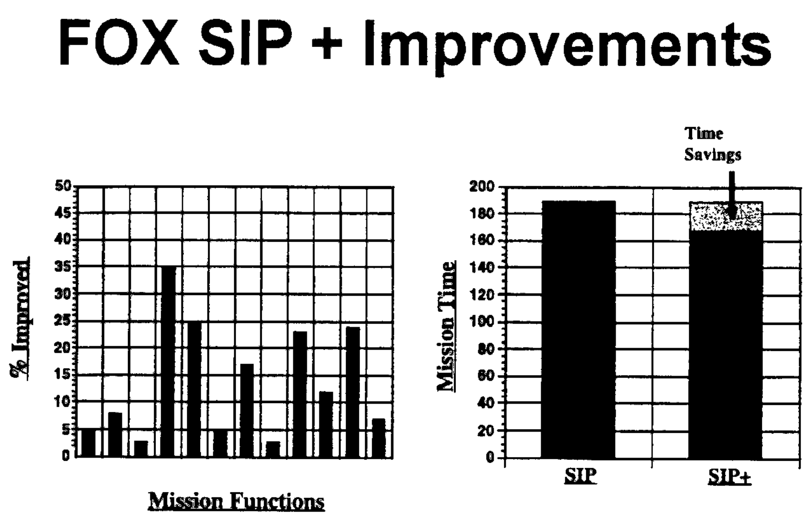


Figure 23. Fox SIP + improvements.

CASE 4: CRUSADER

HRED of ARL at the Ft. Sill Field Element has developed and applied HFI methodology to answer TRADOC questions. This effort had been conducted with the Depth and Simultaneous Attack Battle lab about questions regarding operations of the advanced field artillery system-forward area resupply vehicle (AFAS-FARV), now called Crusader. Pierce (1996) describes how HFI was applied to TRADOC Crusader issues in two major ways: (a) the use of HARDMAN III to answer research questions about Crusader crew characteristics and (b) a Crusader battle lab warfighting experiment. These efforts clearly demonstrate the benefits of answering operational questions about the interaction of soldiers, equipment, and environment in realistic warfighting scenarios.

HARDMAN III Crew Workload Research

The general question for HFI research about the AFAS-FARV was whether the 13 B MOS could accomplish their mission using the AFAS-FARV during sustained operations with regular training (see Figure 24).

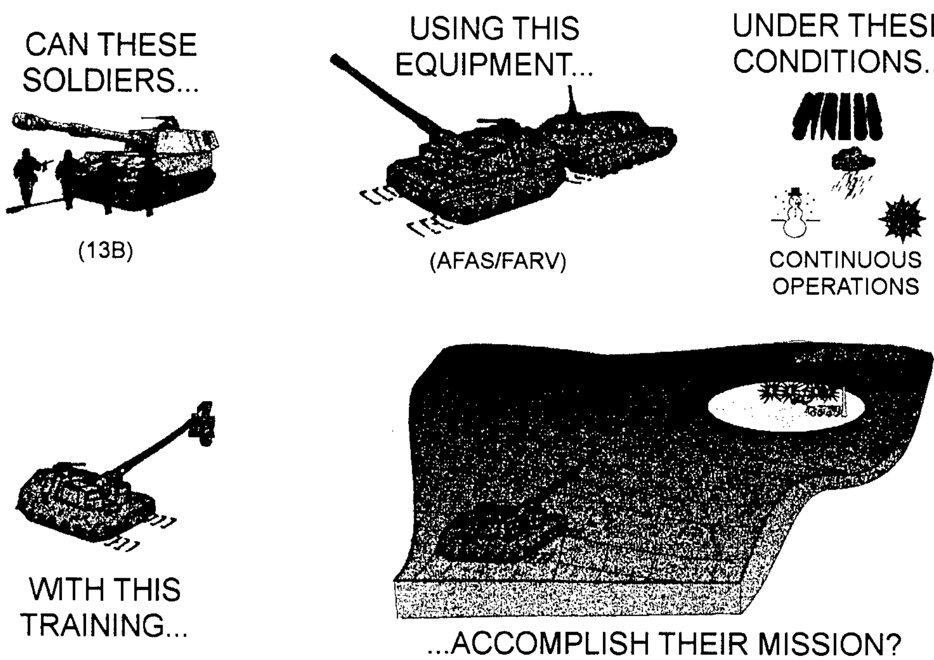


Figure 24. Can these soldiers accomplish their mission?

Three specific manpower and personnel questions were asked of the HARDMAN III analysis:

1. What is the optimal crew size for the AFAS and the FARV?

2. What combination of Armed Services Vocational Aptitude Battery (ASVAB) area composites and area cutoff scores for the AFAS and the FARV results in enhanced mission performance while not restricting the availability of qualified personnel?

3. Is there a basis for selecting an appropriate MOS for the AFAS and the FARV?

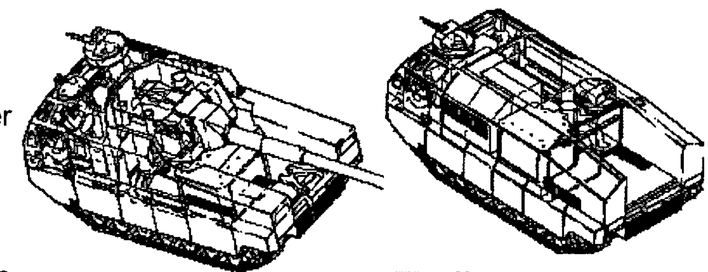
To address the crew size question, HARDMAN III looked at performance of different crew sizes (2, 3, 4) in different environments ("Desert Storm," tropical, NE Asia-Korea) in a range of scenarios (standard, rapid fire, direct fire; degraded operations and FARV upload-manual

and automatic). The crew's performance was also examined for effects of special stressors such as MOPP gear, continuous operations, heat, humidity, cold, wind, and noise (see Figure 25).

Crusader (AFAS-FARV)

HFI Questions:

Crew size & workload under sustained operations



Conditions

- Alternative crew assignments
- Evaluate with sleep deprivation
- Stressors - MOPP Gear/Noise/Heat

Environments

"Desert Storm" Tropical NE Asia-Korea

Scenarios

Standard, Rapid Fire, Direct Fire & Degraded Ops, FARV Upload-Manual and Automatic

Findings

- 2-man crews required 6% more time and made 80% more errors than 3-man crews, on average under all conditions
- FARV crews (2.3, 4-man), using manual upload, met mission performance times less than 1% ol the time
- FARV crews (2 or 3-man), using automatic upload, met mission performance times 100% c the time
- FARV crews (2 or 3-man), in a Desert or Tropica environment made approximately 40% more errors after 48 hours of continuous operations

Figure 25. Crusader (AFAS-FARV).

The HARDMAN III findings are shown in Figure 28. Most significantly, the conclusions reached were

1. With the exception of two-person FARV crews with automatic upload, only three-person crews could perform mission requirements accurately during any of the conditions examined.

2. Automatic upload was essential for FARV. Even a four-person crew could not meet mission performance times in the manual mode. The automatic upload showed that either two- or three-person crews consistently met mission performance times; however,

3. In a desert or tropical environment and after 48 hours of continuous operations, the FARV two- and three-person crews made 40% more errors.

The general conclusion was that the three-person crews were optimal for both the AFAS and the FARV.

To answer the second and third research questions, three-person crews for both AFAS and FARV were assumed. Fewer environments and scenarios were examined and continuous operations were held below 48 hours. Two area composites, field artillery (FA) for the 13B MOS, and operations and food (OF) for the 13M MOS, were considered. ASVAB cutoff scores examined were 85, 95, and 105. The findings support the following ASVAB area conclusions:

1. The AFAS FA for 13B MOS and the OF for the 13M MOS perform about the same in normal operations, but the OF area composite crews produced about 34% fewer mission aborts than FA selected crews. The area cutoff scores recommended therefore were FA 95 and OF 85 or OF 95.

For the FARV, increased aptitude was not significant in improving performance.

2. Although the OF area composite teams could perform adequately with lower cutoff scores and better during continuous operations, the difference was not so great as to select the 13M for Crusader. Use of personnel from both MOSs could increase the availability of qualified personnel. For the AFAS, the standard 13B MOS can perform adequately as long as the cutoff score is 95.

Crusader Battle Lab Warfighting Experiment

The first Crusader battle lab warfighting experiment was funded jointly by TRADOC as a CEP and by ARL as a research program. The first experiment was driven by HFI considerations as an inherent methodology to demonstrate the feasibility of major Army objectives in technology advancement, acquisition reform, and Force XXI objectives (see Figure 26).

Crusader Battle Lab Warfighting Experiment

- Demonstrated that a synthetic environment (including battle staff performance) can provide quantitative assessement of operational concepts
- Demonstrated effectiveness of combined testing and training simulator for Digitized Battlefield
- Answered system specific questions on Crusader performance (with soldier-in-the-loop)
    - A. Crusader can deliver effective fires to defeat projected threat
    - B. Crusader Ammunition Resupply System can support the battle OPTEMPO

Figure 26. Crusader battle lab warfighting experiment.

Synthetic Environment

A new technology (synthetic environment) comprising actual tactical digital systems linked to constructive simulations is considered a first-of-its-kind arrangement. The live systems included such tactical digital systems as advanced field artillery tactical data system (AFATDS), initial fire support automated system (IFSAS), and battery computer system (BCS). The simulations were at two levels, the maneuver battle using the DIS-compliant version of Janus and the fire support processes simulated by the target acquisition and fire support model (TAFSM). The interface between the two simulations was created by an interpreter, World Modeler (see Figure 27). The Janus simulation was staffed by interactor and player staffs using Crusader scenarios. Crusader characteristics were played in the TAFSM model, and soldiers from field artillery units were used to generate and process fire missions, resupply missions, and tactical coordination and movements. HFI personnel at the Ft. Sill Field Element led the experiment, which successfully demonstrated the feasibility of the synthetic environment playing war games of complex battle scenarios with full soldier performance data, including battle staff performance. A critical HFI contribution was the determination of the methodology and metrics with which to evaluate soldier and system performance in the fire support and maneuver battle scenarios. As a result of CEP 1, benchmark performance data were provided for the Crusader system, the state of the art was improved for computer simulations, and lessons learned were documented for future simulation-supported experiments in a DIS environment.

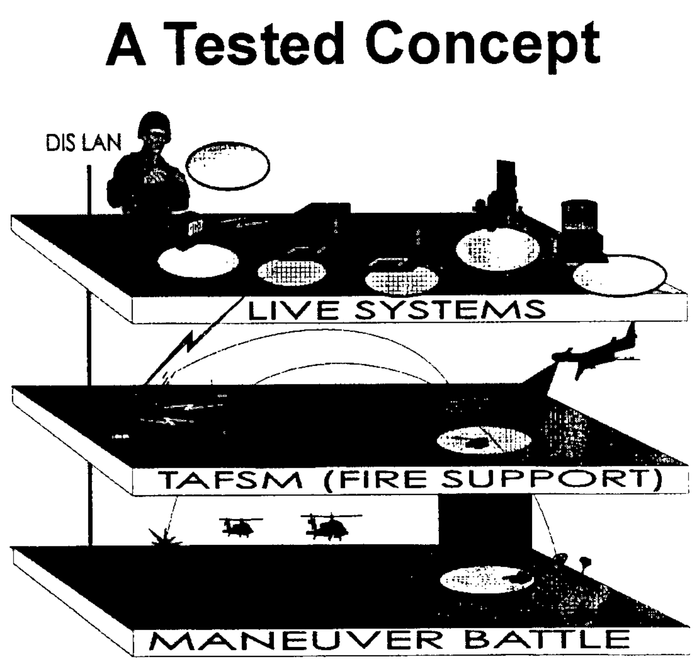


Figure 27. A tested concept.

Training and Testing Simulation

Forty battalion-level staff from a field artillery unit participated in the experiment. The scenario selected represented an artillery battalion performing a direct support role for an attacking brigade and its three task forces. The principal offensive operation was a movement to contact that included a reconnaissance, hasty attack, obstacle breaching, forward passage of lines, and deliberate attack by the maneuver forces. In the experiment, personnel were assigned roles for the maneuver element, the battalion tactical operations center, and each of six platoon operations centers. The subjects employed Crusader in accordance with the Crusader preliminary operational concept, 31 October 1995, and current field artillery doctrine. The 1996 Samaran order of battle and threat doctrine represented the operational forces (OPFOR).

The event stream was those events that comprise a complete command and control cycle, including fire mission processing, survivability and tactical displacements, and resupply planning, coordination, and execution. The TAFSM model performed fire support officer functions and disseminated instructions to players in tactical message format. The study examined implications of Crusader systems in command and control processes, using the event stream. The training and test purpose of the synthetic environment exercise was to stress the unit command and control system, to determine what levels of fire support activity stress this system, and where the system is likely to break when these levels of activity occur. The level of activity was varied through fire missions, movements, platoon operations center performance, and the scenario. An analysis of the experiment defined the tactics, techniques, and procedures (TTPs) used by players and player-controllers. The entire experiment showed the value of the simulation as a trainer for field artillery collective training and as a means of testing alternate Crusader TTPs. Because of HFI involvement, unit performance can now be observed in the various battle games for systems as complex as Crusader operating in a digital battlefield. Shortfalls, gaps, and improvements in the warfighting doctrine can be evaluated and used by TRADOC to propose new doctrine for systems such as Crusader upon fielding.

Crusader Performance Questions

Two principal questions about Crusader performance were asked of the first battle lab experiment:

1. Can Crusader deliver effective fires to defeat the projected threat?

2. Can the Crusader ammunition resupply system support the battle OPTEMPO?

The answer to both questions was in the affirmative, but the experiment provided greater specificity about the relative importance of certain TTPs as well as equipment capabilities and limitations. For example, to deliver effective fires, it was discovered that additional command and control processors were required at battalion and platoon. The techniques for "shoot and scoot" were not only confirmed as sound but were shown necessary to enhance Crusader survivability against counter-fires. Additionally, potential fratricide situations were uncovered and tactics to avoid fratricide developed. Also, for the assurance of effective fires, the experiment found it critical that specific roles and responsibilities for tactical and technical fire control be defined for the platoon centers.

For the resupply system to support the battle OPTEMPO, the experiment confirmed the need for "pooled" resupply vehicles at the platoon level. It was also found that the pooled condition allowed the resupply vehicles' operational cycle (rearm, hide, resupply) to keep pace with conditions of increased fire mission processing.

SUMMARY AND CONCLUSIONS

The four case studies show the vast range and depth of influence that HFI has had upon the Army systems whenever its methodologies have been applied. Generally, performance improved, safety increased, and costs were avoided. The findings of the case studies are summarized for contributions and lessons learned under (a) technology advancements, (b) acquisition process efficiencies, (c) system design enhancements, (d) safety increases, and (e) major returns on investment.

Technology Advancements

The Comanche program demonstrates that technologies across the board are advancing rapidly through the influence of HFI. Not only the human-machine interfaces were advanced to take advantage of the state of the art, but also the entire engine and airframe construction were advanced by the focus on the soldier philosophy. HFI technology itself is advanced by research focused on an operational environment and the human-technology-organizational interfaces. New human figure modeling tools such as those employed on the Fox vehicle are continually being advanced as part of the HFI set of tools to answer such questions as work space layout, egress, and access to equipment in new or modified designs.

Critical to the new digitized battle is the HFI advancement in modeling and simulation. HFI is the crucial link to the confidence required to make models reliable for the environments being simulated (see Figure 28). Such simulations cover a vast array of needs for the Force XXI Army. The Comanche, Crusader, and Fox case studies show the importance of HFI to the capability and validity of those models and simulations directed to questions about systems performance, accelerated acquisition processes, 21st century training techniques, and outcomes in warfighting scenarios.

Human Factors Integration in Simulation

HFI Crucial Link to Confidence in Simulations Used for

- Enhancing the Acquisition System
- Exercising the 21st Century Training Techniques
- Predicting Outcomes in Warfighting Scenarios

Figure 28. Human factors integration in simulation.

The HFI modeling and simulation program currently available at ARL provides a conceptual "build," "test," and "evaluate" tool and has been demonstrated to apply to emerging systems (see Figure 29). Various pieces and their integration on real programs have been demonstrated in the case studies. The human figure model and HARDMAN III were applied to the Fox, whereas HARDMAN III and DIS at the Janus level were successfully applied to Crusader.

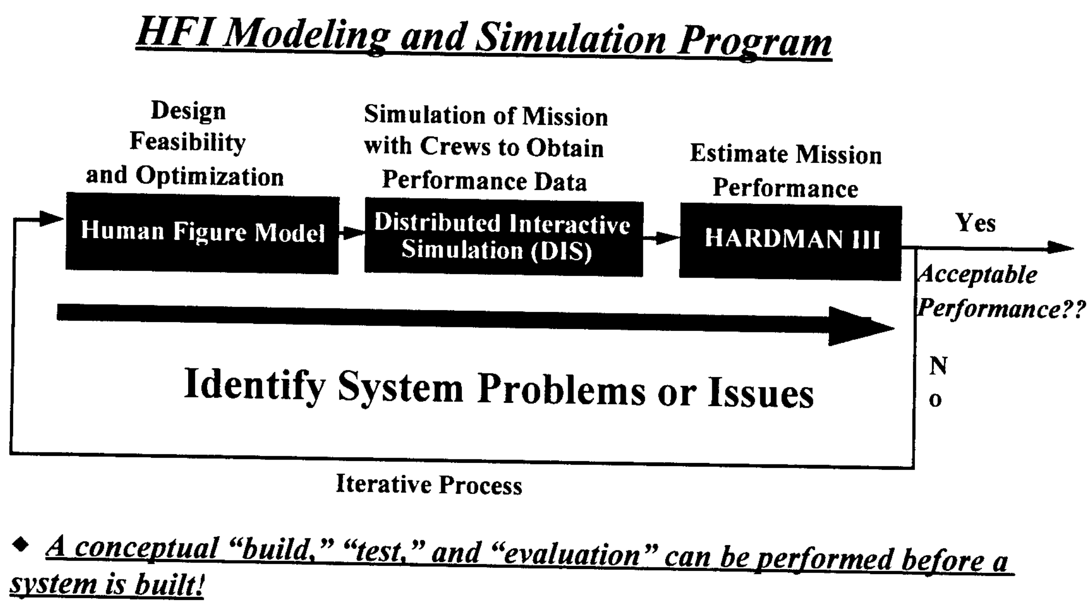


Figure 29. HFI modeling and simulation program.

Acquisition Process Efficiencies

The Comanche illustrated the numerous desirable acquisition processes that were made to work effectively because of HFI influence:

• Advanced modeling and simulation applied to cockpit, engine, and airframe design at early stages of development.

• Unique source selection process - human systems factors evaluated as separate major area *and* integrated throughout all other areas.

• Human-centered technologies and disciplines drove critical decisions throughout the design process.

• TSM-forward concept used actual Army operators and maintainers to communicate "user" needs and concerns to contractors at contractors' location.

• System performance defined to include operators' and maintainers' performance as well as equipment performance. This definition carried through operational T&E measures of system performance.

The Fox vehicle case study shows that the benefits to the acquisition process are not limited to new systems. The HFI modeling program can be applied anywhere from Milestone (MS) O to MS IV (see Figure 30). The Fox vehicle also shows the major benefits to non-major systems as well the ability of HFI to focus T&E more effectively.

Modeling within the Acquisition Cycle
(Anywhere!!)

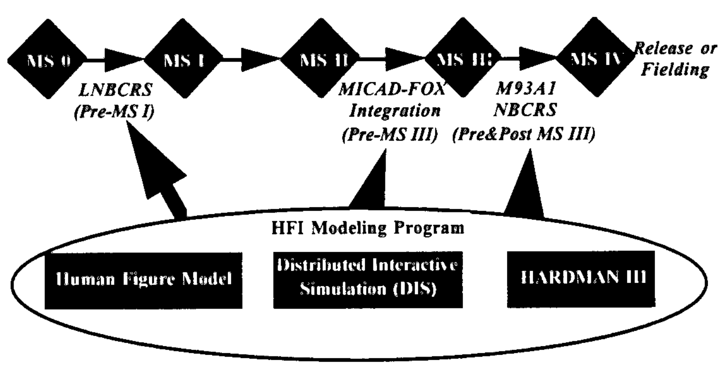


Figure 30. Modeling within the acquisition cycle (anywhere!!).

The Crusader illustrates how TRADOC can employ HFI to evaluate operational concepts, improve the criteria for reducing costs of operational T&E, and make training and

testing more effective by integrating real and simulated systems in a complete battle lab environment.

System Design Enhancements

The case studies indicated clearly that HFI can be applied to enhance system designs appreciably, regardless of the stage of development or how large the system is. Longbow Apache HFI made more than 160 critical design improvements for the period evaluated. The ACAT-III Fox vehicle could not have performed its mission to meet system requirements if HFI had not designed a new workstation. These two systems were, however, modifications of existing systems, so the HFI potential was limited. To appreciate the full impact of HFI potential on system design, the Comanche is without comparison. A few of the improvements are as follow:

Significant Comanche HFI Design Improvements

- State-of-the-art crew station design decreasing pilot workload while increasing mission performance.
- Superior modular main rotor blade design with reduced acoustic vibration, automatic rotor tracking, reduced maintenance, greater transportability, and an approximately $150 million manpower life cycle savings.
- Tail rotor designed to be eight times safer than conventional designs.
- Portable maintenance aid laptop computer to diagnose systems failure, accumulate critical flight and maintenance data, and replace all technical publications.
- Line-replaceable modular design for mission equipment packages for functional partitioning and diagnostics capability.
- Central box main structure, which acts as primary load-bearing carrier for high structural integrity and allows exterior skin to have 50% access panels.
- Enhanced drive train with 73% fewer parts than Blackhawk and 62% fewer than Apache.
- T-800 modular engine design with increased reliability and 40% reduction in maintenance man-hour requirements.
- Tool set with only 50 tools, compared to more than 150 for other helicopters, with only 22 of the 50 peculiar to Comanche.

Safety Increases

Safety was greatly improved by the MANPRINT teams on both the Comanche and Apache. Comanche showed 91 lives saved and 116 disabling injuries avoided from HFI designs, compared to the predecessor aircraft. The Apache study did not calculate the number of lives and disabling injuries avoided, but two of the five PICs, if they had not been corrected, would have undoubtedly contributed to unnecessary loss of lives and disabling injuries.

Major Returns on Investment

The three case studies with quantitative analysis of costs and savings make an interesting comparison. The Comanche offers both the greatest savings to investment and total costs avoided (see Table 3). The Apache Longbow provides a very commendable savings and return on investment. Both Comanche and Apache returns are spread over 20 years. The advantage of the investment in Apache is that the investment is considerably smaller and the return will begin earlier as the Longbow is started to be fielded in FY 98. The Fox vehicle is perhaps the most interesting for considering the future Army with few new major systems and major modifications. Systems such as Comanche and Apache represent an acquisition system of the past, not the future. Program managers and TRADOC system managers should be aware of the tremendous advantages that HFI offers to the smaller but far greater number of systems that can be improved for soldier use as well as saving resources in the near term. Fox showed that programs can save considerable program costs if HFI disciplines and technology have played a role in design, modeling, and simulation.

Table 3

Major Returns on Investment

System	Cost savings	Investment	Savings to investment ratio	Time (years)
Comanche	\$3.29 B	\$74.9 M	43.9:1	20
Apache Longbow	\$268.8 M	\$12.3 M	21.8:1	20
Fox	\$2-4 M	\$60 K	33.0:1	1

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13. ABSTRACT *(Maximum 200 words)*

This report documents and, to the degree possible, quantifies the benefits of human factors integration (HFI) effort to selected Army programs. Four Army weapon systems were identified for documenting HFI lessons learned and quantitative benefits. These systems are two aviation systems, Comanche and Apache; one nuclear, biological, chemical (NBC) reconnaissance vehicle, Fox; and the Army's advanced howitzer program, Crusader. The Comanche aircraft provides the most comprehensive lessons learned for HFI, based on its application of the Army's manpower and personnel integration (MANPRINT) program from its inception. The Apache helicopter provides some quantitative examples of benefits from HFI applications on design and development of changes to a system already in the Army inventory. The Fox reconnaissance vehicle (XM93E1 NBC) demonstrates quantitative benefits and lessons learned from HFI applications on a non-major system. The Crusader was chosen because it illustrates the critical role played by HFI technologies in conducting realistic battlefield scenarios in war games.

Attention is given to the effects of HFI in five major areas:

1. The acquisition process
2. System design and development
3. Operational performance and testing
4. Cost avoidance
5. Safety benefits

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